MR sign reversal in various spin valves and tunnel junctions (non-ferroelectric)

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Prof. Xu’s group meeting
Band alignment
Bias dependent MR is related to the Co band alignment.
FeCo(17nm)/Alq3(150nm)/LiF(1nm)/NiFe(20nm)

LiF reversed MR sign

Polar interface shifted the band alignment.

NatMater 10, 39 (2011)
Band shift with CoO forming

- CoO dipole shifts the band.
- More CoO, more shift.
LSMO(50nm)/Alq3(30nm)/Al(0-6nm)/Co(20nm)

0nm Al: Negative MR ratio decays faster as increasing positive voltage
With Al insertion >2nm, resistance increases, rectification emerges, and MR sign reversed at positive biases.

APL 104, 262402 (2014)
Interfacial bonding and s/d electrons
Ni$_{80}$Fe$_{20}$(12nm)/Ta$_{2}$O$_{5}$(0.5-1.5nm)/Al$_{2}$O$_{3}$(0.5-1.5nm)/NiFe(8nm)

A: Ta$_{0.5}$/Al$_{0.5}$
B: Ta$_{0.75}$/Al$_{0.75}$
C: Al$_{0.5}$/Ta$_{0.5}$
D: Ta$_{0.5}$
E: Al$_{1.25}$

Inverse MR when Ta is positively biased.
Ta$_{2}$O$_{5}$/electrode shows reversed spin polarization and can be changed by bias.

S, d bonding.

\[
\frac{\Delta R}{R} = \frac{R_{AP} - R_{P}}{R_{AP}} = \frac{2P_{1}P_{2}}{1 + P_{1}P_{2}}
\]

PRL 82, 616 (1999)
LSMO(35nm)/STO(2.5nm)/Co(30nm)/Au(5nm)

d electrons carry spin.
s electrons won’t carry spin.
Interfacial spin hybridization
LSMO(100nm)/Alq3(150nm)/Co(10nm)/Al(10nm)

Different junctions: R ranges huge!

JAP 103, 093720 (2008)

80% samples show negative MR, symmetric IV
Some: MR sign changes with polarity. Thinner Co, bigger $H_c$.

JAP 103, 093720 (2008)
LSMO/Alq3/Co

<10nm junction: positive MR

Strong bias and temperature dependence.

JAP 103, 093720 (2008)
Hybridization induced MR inverse at Co/Alq3

MR sign was reversed by inserting a layer between Co and Alq3
oxygen vacancy at LSMO interface
LSMO(20nm)/Alq3(12-60nm)/MgO(3nm)/Co(30nm)/Ru(10nm)

Submicron sample, 60% no pinhole; others show only one pinhole.

RS and MR reversal happens at the LSMO interface.

LSMO(20nm)/Alq3(12-60nm)/MgO(3nm)/Co(30nm)/Ru(10nm)

AIP Advances 6, 045003 (2016)
Replace Alq3 by H2PC

RS and MR sign reversal observed
Pinholes and localized states in barrier
At higher bias, “hot electron” transport through the pinholes results in heat dissipation within the nanocontact region just outside the ballistic channel. The backscattering into the narrow channel increases due to larger phonon density of states at the nanocontact.
Ni/NiO/Co: Resonant tunneling through an impurity state

Big area will average out the impurity state position distribution and result in small positive MR effect.

\[ G(E) = \frac{4e^2}{h} \frac{\Gamma_1 \Gamma_2}{(E - E_i)^2 + (\Gamma_1 + \Gamma_2)^2} \]

the energy of a localized state lies close to the \( E_F \) and resonant tunneling dominates direct tunneling
Resonant tunneling through a midgap defect band

8-μm² MnAs/AlAs (4 nm)/MnAs

$$G_{\sigma\sigma'}(\epsilon - \epsilon_c) = \frac{4e^2}{h} \frac{\Gamma_{L\sigma}\Gamma_{R\sigma'}}{\Gamma_{L\sigma} + \Gamma_{R\sigma'}} \times \frac{\Gamma_{L\sigma} + \Gamma_{R\sigma'} + W}{[2(\epsilon - \epsilon_c)^2 + [\Gamma_{L\sigma} + \Gamma_{R\sigma'} + W]^2}$$

16-μm² MnAs/GaAs (7.5 nm)/MnAs

Thicker one benefits resonant tunneling compared with direct tunneling.

PHYSICAL REVIEW B 72, 081303R 2005
Resonant tunneling using Ni tip STM

MR show sign reversal with bias.

J. Appl. Phys. 101, 09B102 2007